

CLAIM MAKING AS A TOOL FOR ANALYZING STUDENT THINKING IN STEM CONTEXTS

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We articulate a framework for delineating student thinking in active, STEM-rich learning environments. Researchers have identified ways of reasoning that relate to specific content areas and practices within each of the STEM disciplines. However, attempts at characterizing student thinking in transdisciplinary STEM environments remains in its infancy, in need of theoretical and analytic frameworks to support this emerging research area (Li et al., 2019). This paper advances the field along both of these dimensions by articulating an analytic framework for student thinking in STEM contexts and operationalizing it through an analysis of two groups of students in elementary, informal learning situations. Our results suggest that student thinking, in these environments, is often grounded in personal experience and authority and consists of a rich mix of general and disciplinary-oriented reasoning. Implications are provided.

Keywords: Integrated STEM, Cognition, Reasoning and Proof, Problem-Based Learning

Perspectives

Is STEM a discipline in and of itself? What is integrated, multidisciplinary, or transdisciplinary STEM? While perspectives on the precise nature of STEM vary widely (Holmlund et al., 2018), we believe that conceiving of STEM as a stand-alone discipline of study can be problematic given the differences found in the epistemological orientations of the individual STEM disciplines (Kelley & Knowles, 2016; Ortiz-Revilla et al., 2020; Slavit et al., 2021). For example, mathematical truth is found by logical deduction based on a set of axioms, scientific truth is based on systematic observation and an analysis of available evidence, and engineering truth is often subjectively decided by the client or what constitutes a *best* design. Given this variety of epistemologies, conceptualizing STEM as a stand-alone discipline can be rather difficult; characterizing *STEM thinking* can be even more difficult.

However, we do believe that student thinking in STEM contexts can be analyzed in a systematic manner. Through the analysis of multiple learning situations, we have determined that a fruitful avenue of research lies in the identification and analysis of student claims made in STEM contexts. Specifically, we have developed an analytic framework designed to characterize the nature of the claims, evidence, and reasoning that surface in student comments and/or activity while engaged in active, group-based STEM learning activities. This approach allows us to draw from the plethora of existing reasoning types inside the individual STEM disciplines, but also provides an avenue to explore the kind of thinking that might be unique to STEM learning contexts. While we align ourselves most closely with transdisciplinary STEM due to its synergy with project-based learning environments (Vasquez, 2014), due to space limitations we refer broadly to “STEM environments” rather than attempt to make distinctions between integrated, multidisciplinary, and transdisciplinary perspectives on STEM.

Disciplinary STEM Reasoning

Over the past decades, educational researchers from individual disciplines have identified specific kinds of reasoning related to thinking and problem solving in mathematics, science,

engineering, and technology. Hjelte et al. (2020) conducted a systematic review of the types of reasoning found in mathematics education research and identified spatial sense, quantitative reasoning, additive/multiplicative reasoning, proportional reasoning, and algebraic reasoning as common examples of student reasoning grounded in specific mathematical ideas and concepts. Hjelte et al. (2020) also mentioned informal inferential reasoning and transformational reasoning as commonly researched areas. In engineering education, Worsley and Bilkstein (2017) identified four types of reasoning observed in student solutions to design tasks. These were unexplained reasoning, materials-based reasoning, example-based reasoning, and principle-based reasoning. Worsley and Bilkstein (2017, p. 64) described the latter as “working forward from deep structural features.” In science education, Kind and Osborne (2017) explored six styles of reasoning, which they labeled mathematical deduction, experimental evaluation, hypothetical modeling, categorization and classification, probabilistic reasoning, and historical-based evolution. Kind and Osborne discussed the presence of these types of reasoning in science education, such as the predominance of hypothetical modeling and experimental evaluation in the traditional scientific method (Windschitl et al., 2008). However, while student thinking about specific scientific ideas has been researched, there is a general lack of content-specific frameworks for analyzing thinking in science education beyond the levels of Earth, physical, and life sciences (Roehrig et al., 2021) or key “cross-cutting concepts” (NGSS Lead States, 2013). For example, while proportional reasoning exists as a construct in mathematics education, constructs such as *velocity reasoning* or *organismic reasoning* are not found in the science education literature. Engineering education is also generally devoid of such constructs. Further, we believe that all four types of engineering-based reasoning described by Worsley and Bilkstein (2017) are compatible with the other three STEM disciplines and, in addition to their applications to the discipline of engineering, can be considered as more general types of STEM reasoning.

While not exhaustive, the above discussion of disciplinary reasoning suggests that there are multiple reasoning types inside the individual STEM disciplines which can support an analysis of STEM thinking. Further, some of these are specific to an aspect of a discipline, the overall discipline, or are broad enough in nature to generalize across the disciplines, such as example-based or discipline-based reasoning.

Claim Making as a Tool for Analyzing STEM Thinking

Is STEM reasoning a combination of the above kinds of reasoning? Is it something that transcends this collection? Space does not allow an adequate response to these questions, nor for a thorough theoretical discussion of the precise nature of STEM. However, we now provide a discussion of how we approached the task of analyzing STEM thinking.

Drawing from Toulmin (1958) and a variety of perspectives on student claim making in science (McNeill & Krajcik, 2012), mathematics (Kazemi et al., 2021), engineering (Siverling et al., 2019), and technology, we approach our analysis of student thinking in STEM contexts by focusing on the nature of the student claims, evidence, and reasoning that surface during active, collaborative learning experiences. We view a claim as the onset of an argumentation process, and reasoning as a tool that can be used to support or challenge the validity of the claim (Gray & Kang, 2014; Lee et al. 2014). Because claims involve positioning, they elicit arguments that utilize evidence and reasoning in support of that position. Further, claims are often contextualized and therefore dependent on the perspectives of the claimer (Toulmin, 1958; Forman et al., 1998).

A claim can consist of a relatively short, concise statement made by an individual. However, claims can be more complex and consist of a set of statements and actions by an individual or collection of individuals. When such statements and actions are related in nature or substance, we

consider the collective a *claim sequence* and treat it as a single claim for coding purposes. Note that challenges and differing perspectives might exist inside a claim sequence.

Certain types of claims were excluded from our data sets. Claims not relevant to the current STEM-based activity were not recorded, nor were claims that were procedural in nature or did not add significantly to the disciplinary value of the student activity. For example, a statement such as “I think we need to reread the directions” was not identified as a claim. Restated or repeated claims were also not recorded. Because gestures and other non-verbal student activity can be an important part of the claim-making process, and even fully constitute a claim, we took care to incorporate descriptions of these non-verbal activities when identifying and describing claims.

Methods

Drawing on a sociocultural perspective (Vygotsky, 1978; Cobb, 1992), this qualitative research study is grounded in naturalistic observations (Lincoln & Guba, 1985) of student activity. This paper reports on work from a larger project that analyzed over ten learning situations across Grades 1-12 in both formal and informal learning environments. In this paper we focus on two learning episodes, both of which involved groups of elementary students working a STEM-rich task in an informal learning environment.

Settings and Participants

Two videos of small-group learning experiences were selected for analysis and comparison. The two videos had many similarities, including students at the elementary level, an informal and active learning environment, and the students working in a collaborative manner. However, key differences in the learning experiences included the nature of the STEM content emphasized and the nature of the materials provided to support the student activity. Further details of the two videos can be found in Table 1.

Table 1: Student Learning Activity Descriptions

Video	Brief Description	Setting	Participants	# of Claims	Length
Dash Coding	One group of students design a path and then program a robot (Dash) to follow a path created by another group.	Informal; Free time in TinkerLab in elementary school	5 th grade students; 3 boys and 1 girl	36	18 minutes
Roller Coaster Wall	One group of students used grooved rubber strips and other materials to build a “roller coaster” affixed to a wall.	Informal, after school; hosted by local museum	2 nd grade students; 3 boys	29	32 minutes

Data Collection

Both episodes were videotaped using a GoPro camera attached to the chest of one of the student participants. This allowed for a unique view of the activity as well as high-quality sound. For both videos, two of the three authors independently identified the claims and claim sequences articulated by the student participants, and then transcribed the student comments into the first

column of an Excel spreadsheet, the top row of which contained the names of all codes (see below). As noted above, both the words and actions that constituted a claim were recorded. Therefore, our unit of analysis was a *claim* or *claim sequence*, as described above. Once the pair of authors had individually recorded all claims in a given video, they met to compare the claims they each identified. Claims were removed, added, and modified based on these discussions. The two videos and the accompanying set of transcribed claims represent the data used in this paper.

Data Analysis

All claims were coded using an analytic framework we developed from the literature as well as our analysis of over ten videotaped learning activities. The framework includes a variety of individual codes related to the claims, evidence, and reasoning that surfaced during student activity. Further details of the development and nature of the codes have been provided elsewhere (Slavit et al., 2022), but the following is a summary description:

Claim Codes:

Explicit/Implicit – if the claim has been overtly communicated using words and/or symbols
 Formal/Informal – if the claim uses academic language or is grounded in disciplinary practices
 Tentative/Certain – if the claim is made with confidence
 Novel/Challenge – if the claim introduces a new idea or perspective into the activity
 Disciplinary – if the claim is grounded in math, science, engineering, or technology contexts

Evidence Codes:

Fact – use of a past-learned fact, example, or definition
 Prior Experience – use of an event that occurred prior to the learning experience
 Test – use of a recently-occurring event
 Perception/Observation/Manipulation – use of in-the-moment event or “seeing in the moment”
 None or unable to determine

Reasoning Codes:

Explicit/Implicit – if the reasoning has been overtly communicated using words and/or symbols
 Experiential/Abstract – if the reasoning is based on observation/evidence or theory
 Personal/External Authority – if the source of the reasoning comes from the claimer
 Disciplinary – if the reasoning is grounded in math, science, engineering, or technology contexts
 General - principle-based, test-based, experience-based, unexplained
 Mathematically-grounded – spatial, numeric, algebraic
 Scientifically-grounded – cause-effect, analogic
 Engineering-grounded – constraints-based, materials-based
 Technology-grounded – algorithmic
 Other – as these are identified and described, new categorizations are continuously considered

The authors used both the transcriptions of the claims and the video to make coding decisions. First, one or both codes from each of the first four pairs of claim codes were applied, followed by as many disciplinary codes as were relevant to the nature of the claim. If the source of evidence was able to be determined, then one or more of the evidence codes were applied. Finally, to code the reasoning, one or both codes from each of the first three pairs of reasoning codes were applied, followed by as many disciplinary codes as were relevant to the nature of the reasoning. Then, any general (e.g., principle-based, test-based) or discipline-specific (e.g, spatial, cause-effect) reasoning codes were applied as relevant.

For both videos, the two authors who created the set of transcribed claims individually coded the set of claims for that video using the above procedures. Interrater agreement was calculated using exact coding comparisons, dividing the number of agreements by the number of coding decisions. Interrater agreement across the two videos was 85.8%. The pairs of authors met to resolve the discrepancies in the codes, producing the final results.

Results

Tables 2 and 3 illustrate the results for both the Dash and Roller Coaster Wall videos, respectively, related to the nature of the claims, evidence, and reasoning operationalized by the student participants. Note that some coding pairs or sets do not always add to 100% due to instances of double coding. This usually occurred in an extended claim sequence involving multiple comments or actions by more than one individual. For example, one student might initiate a claim using formal language, and another might immediately provide a challenge to the claim using informal language or a contradictory action. This situation would produce double codes for both of these coding pairs.

Table 2: CER Codes for Dash Learning Episode

36 Claims or Claim Sequences								
Claim		Evidence		General Reasoning		Discipline-Oriented Reasoning		
Explicit	35	Fact	0	Explicit	11	Math	Spatial	22
Implicit	2	Prior Exp	2	Inferred	26	Math	Numeric	2
Formal	14	Test	11	Experiential	36	Math	Algebraic	0
Informal	27	Perc/Obs/Man	30	Abstract	0	Science	Cause-effect	3
Tentative	10	None or N/A	3	Pers Auth	35	Science	Analogic	0
Certain	31			Ext Auth	2	Engineering	Constraints	6
Novel	35			Science	0	Engineering	Materials	5
Challenge	12			Math	20	Technology	Algorithmic	2
Science	0			Engineering	24	Multiple Disciplines		19
Math	23			Technology	13			
Engineering	23			Principle	5			
Technology	17			Test	10			
				Experience	2			
				Unexplain	3			

Table 3: CER Codes for Roller Coaster Building Learning Episode

29 Claims or Claim Sequences								
Claim	Evidence			General Reasoning		Discipline-Oriented Reasoning		
Explicit	28	Fact	5	Explicit	8	Math	Spatial	12
Implicit	1	Prior Exp	1	Inferred	21	Math	Numeric	0
Formal	1	Test	13	Experiential	27	Math	Algebraic	0
Informal	28	Perc/Obs/Man	26	Abstract	5	Science	Cause-effect	14
Tentative	5	None or N/A	2	Pers Auth	28	Science	Analogic	1
Certain	26			Ext Auth	1	Engineering	Constraints	1
Novel	24			Science	8	Engineering	Materials	10
Challenge	6			Math	1	Technology	Algorithmic	0
Science	8			Engineering	27	Multiple Disciplines		9
Math	1			Technology	0			
Engineering	29			Principle	7			
Technology	0			Test	17			
				Experience	1			
				Unexplain	12			

Overall, several commonalities emerged in the nature of the claims, evidence, and reasoning across the two learning episodes. The nature of the claims made by the students were mostly explicit, informal, and certain. These data collectively indicate that the students felt confident in their own ideas but chose to express them using language and gestures outside of the disciplinary registers. We also see that the nature of the activity influenced the disciplinary nature of the claims. For example, all student claims in the Roller Coaster activity related to an aspect of the engineering activity of the student work, which was framed by the design and building of a structure. However, student claims in the Dash video relied more on multiple disciplinary influences, drawing heavily from mathematics, engineering, and technology.

The evidence used to support the claims came mostly from tests and observations. This suggests that student reasoning was mostly emergent, influenced by in-the-moment advances in the student activity. Finally, the reasoning used to support the claims was mostly inferred and came from personal authority as opposed to an external source. The reliance on personal authority is in line with the prior result regarding the influence of in-the-moment activity as a source of evidence. In other words, the role of personal authority in the claims likely emerged, in part, from the personally constructed nature of the evidence.

The large number of claims in the Dash video that drew on more than one discipline emerged from the synthesis of mathematics, engineering, and technology embedded in the learning experience. The students were continuously measuring angles, considering design elements of the path of a robot, and programming path directions. This led to more than 50% (19 of 36) of the claims incorporating more than one STEM discipline. A smaller percentage of claims (31.0%, 9 of 29) from the Roller Coaster video incorporated more than one STEM discipline, and these were mostly grounded in engineering and science concepts and practices. For example, at the very beginning of the Roller Coaster activity, the following claim sequence occurred:

Gary: Now we need to go up. [referring to the design of the roller coaster path]

Steve: No, we can't do it or else it won't go. [referring to the need for speed to continue an upward path]

Gary: We need to just make it straight.

Steve: That would make it straight down like a roller coaster. [added rubber strip to extend the roller coaster path down]

Gary: And then up just a little bit...Because I imagine it has a lot of energy in this.

Here we see a rich blend of design-based thinking and scientific properties related to motion in the claims being made throughout this sequence. We also see both novel and challenge claims, the use of both informal and informal language, and a reliance on past tests and current observations to support the STEM-based reasoning. Approximately five minutes later, the following claim sequence occurred that was again grounded in both science and engineering concepts and practices:

Gary: We should start it over here. [placed rubber strip to reaffirm intention] So I can put one in over here. I am just keeping it here, and it should be angled downward. It should be angled down to give it more energy.

A key difference between this claim and the initial example lies in the degree of abstract thinking and use of formal language used by the student. Rather than relying on a test to make a claim about the utility of the design, Gary drew from his own knowledge of properties of motion and force to make a claim about the increase in energy due to the proposed design. This type of claim was much less common throughout both of the learning experiences.

There was an approximate 1:3 ratio in the number of challenge claims to novel claims in the Dash video, with a ratio of 1:4 for the Roller Coaster video. The presence of challenge claims in both learning episodes is important, as it signifies moments of disagreement, opening up opportunities for argumentation and further learning. For example, the following discussion occurred early in the Dash video after a test run of the robot:

Ryan: I think the 45 degrees might be too much.

Alex: No, because that means he'll only have to do a tiny turn. [moves Dash in air to mimic this]

Ryan: Ok, then we have to do a turn left 45 degrees or turn left 30 degrees.

Alex: Move forward 10 cm.

[Alex reprograms, then Dash runs]

Alex's challenge of Ryan's initial claim led to refinement of their programming, including changes to both angle and length. Alex's spatial sense led to the use of a slightly smaller angle, a claim articulated by both actions and gestures. Ryan was convinced and further advanced the claim with a statement about the length of the robot's path. Aspects of mathematics, engineering, and technology appear in both the nature of the claims and the associated reasoning.

Discussion

This paper provides a framework for analyzing student thinking in STEM environments and provides empirical evidence on the nature of student thinking during two STEM learning experiences. The two learning episodes have unique features, and we do not claim to have captured the full range of thinking that happens within STEM learning environments. However, as demonstrated here, our framework is useful for looking at the nature of thinking from the perspective of student claim making, and our results provide insight into the nature of student thinking in STEM environments.

In these two examples from elementary, informal settings, there are many consistencies. Of special importance is the use of in-the-moment activity (usually test and observation) as the

primary source of evidence, and the dominant role of explicit, certain, and informal language in the student claims. This collectively produced an experimental quality to the evidence and reasoning. Our results suggest that student thinking, in these environments, is often grounded in personal experience and authority and consists of a rich mix of general and disciplinary-oriented reasoning, as well as the use of multiple disciplines inside a single claim. In contrast to the nature of the claims, most of the reasoning was not explicitly stated and had to be inferred. Educators should note these thinking tendencies and attempt to nurture and build on these practices during student activity.

While only one claim in the Roller Coaster video was coded as mathematical in nature, 12 instances of spatial reasoning occurred throughout the activity, often tightly connected to reasoning from other disciplines. In contrast, there were 23 claims and 20 examples of reasoning that incorporated mathematics in the Dash video. Most of this reasoning also involved spatial reasoning related to the nature of the robot's path, but some instances of numeric reasoning, usually associated with measurement, also occurred. Specifically, the students in the Dash video often relied on estimation or trial-and-error, rather than careful tool-based measurement, exhibiting a strong, intuitive sense of angle and length estimations. Much of the reasoning was also done in conjunction with engineering-based reasoning about the design of the path and technology-based reasoning related to the programming parameters of the robot.

Contexts, participants, materials, and content all played roles in the emergence, nature, and evolution of the thinking observed, including thinking that drew from multiple disciplines. Although the learning experiences had a clearly defined goal, they were generally ill-structured. An initial prompt and materials were provided, but then very little subsequent direction was provided for the students to follow. This afforded a personal dimension in the student thinking, as the students had freedom to explore the context, develop their own ideas, and think collaboratively. While the inherent nature of each activity placed some degree of definition on the nature of the disciplinary content that emerged, the students were also free to draw on their formal and informal disciplinary knowledge in a manner of their own choosing. This is quite different from the more siloed and structured learning environments found in many classrooms. As a result, the student thinking incorporated claims that often involved more than one disciplinary influence and were initiated by ideas and activities generated by the students.

While the above discussion is helpful, we call for more examples of STEM thinking in a variety of contexts to support educators in building learning experiences more in line with the ways in which students think about disciplinary and STEM ideas. For example, Foster et al. (2022) drew on Walton's (1998, 2022) argumentation framework to analyze student dialogue in elementary STEM classrooms. Similar to our results, they found multiple disciplines emerging in student comments, but their use of Walton's framework allowed for an analysis that further discerned the nature of the arguments. For example, they identified arguments that sought out information or helped to determine a best course of action as most common. We urge others to extend on these existing frameworks and further explore the student aspects of claim making in STEM environments.

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